

A transceiver for 137 kHz

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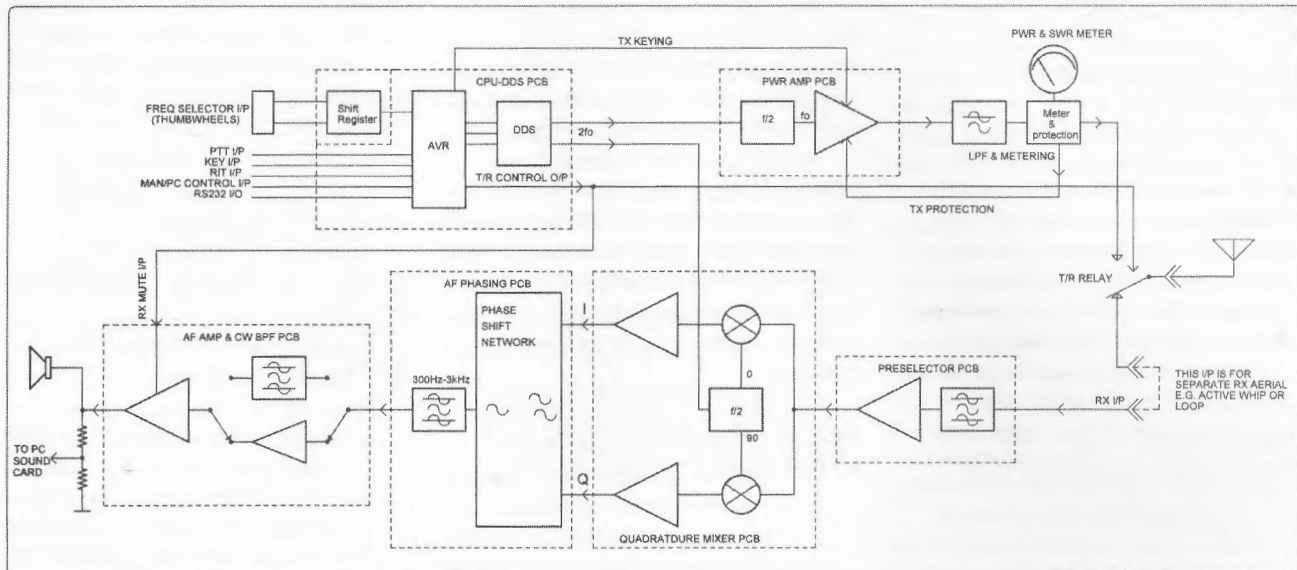


Figure 1: Block diagram of the transceiver. For clarity the power supply to each module is not shown.

This article describes a transceiver for use on the low frequency band that was recently allocated to Australian amateur operators. This band has a number of peculiarities when compared to other amateur bands:

1. The band is only 2.1 kHz wide covering 135.7 kHz to 137.8 kHz. This limits transmission modes to a variety of narrow band digital modes, with some form of Morse code being the most popular at present.
2. Radiated power is restricted to one watt EIRP. This is not much of a restriction, given the typical inefficiency of any antenna that most amateurs are likely to erect; even radiating a few tens of milliwatts is a challenge.
3. Local and atmospheric noise levels are very high, particularly in summer. The ability to receive signals is generally limited by noise rather than receiver sensitivity.
4. Very little commercial equipment is available that can be directly used on the band, thus 'home brew' equipment still reigns

supreme. A typical setup might be a transverter based around a standard HF transceiver, with a substantial homebuilt power amplifier to overcome antenna inefficiency. Less common is the construction of a complete transceiver.

Despite all of these challenges, it is a fascinating band with many enjoyable aspects. Reasonable DX contacts can be had using one of the various digital modes and reliable ground wave communications can extend many hundreds of kilometres.

As I have had good experiences using direct-conversion phasing type receivers and Direct Digital Synthesiser oscillators, I chose to build a complete transceiver using that technology. Previous projects using phasing techniques (References 1 and 2) provided suitable circuit modules that could be duplicated for use in the receiver and transmitter, leaving only a number of modules to be designed 'from scratch'. The following pages will describe each major section of the unit. Figure 1 shows the block diagram of the transceiver with each

of the major modules shown within dashed lines. Exact inter-connection details have been omitted and it is hoped that the connections between modules are self-explanatory.

There is quite a lot of information regarding the 137 kHz band available. The RSGB has published an excellent book (Reference 3) which covers all aspects of LF operation and equipment. It is essential reading if you intend to operate on the band. Many of the circuits described in this article were based on previously published designs which were then adapted and modified to suit local availability of components.

Features and description of the transceiver

Frequency range

135.700 kHz to 137.800 kHz. Operating frequency is set using 'thumbwheel' switches and the minimum adjustment step is one Hz. Frequency stability is approximately 2.5 parts per million and this is an important aspect to consider for the QRSS modes as the bandwidths

used are only a fraction of a Hertz, so the ability to accurately set your frequency – and to stay on it – is vital if a contact is to be successful.

Transmitter

A push-pull class D design with a maximum continuous output power of 220 watts into a 50 ohm load. A five pole low pass filter ensures a clean RF output. A front panel meter shows RF output current and forward and reflected power.

Receiver

An 'image reject' direct conversion design which offers low noise with excellent dynamic range. No AGC is provided and it appears unnecessary, particularly when using the QRSS modes.

Operating modes

1. Standard CW - either hand sent or from an attached PC at 6 or 12 wpm.
2. Slow CW – known as QRSS – from 3 to 120 second dot lengths.
3. Differential frequency CW - where the dot and dash elements

are sent as slightly different frequencies. Dot and dash lengths are the same in this case.

4. Castle CW – Dot and dash are sent as different frequencies with an additional frequency shift depending upon the time relationship of the character elements. This mode is probably the most time efficient and easiest to read of the QRSS modes.
5. Sequential multi-tone Hellschreiber – an 'image' based transmission mode where each character is sent as an array of pixels that can be read directly from the computer screen.

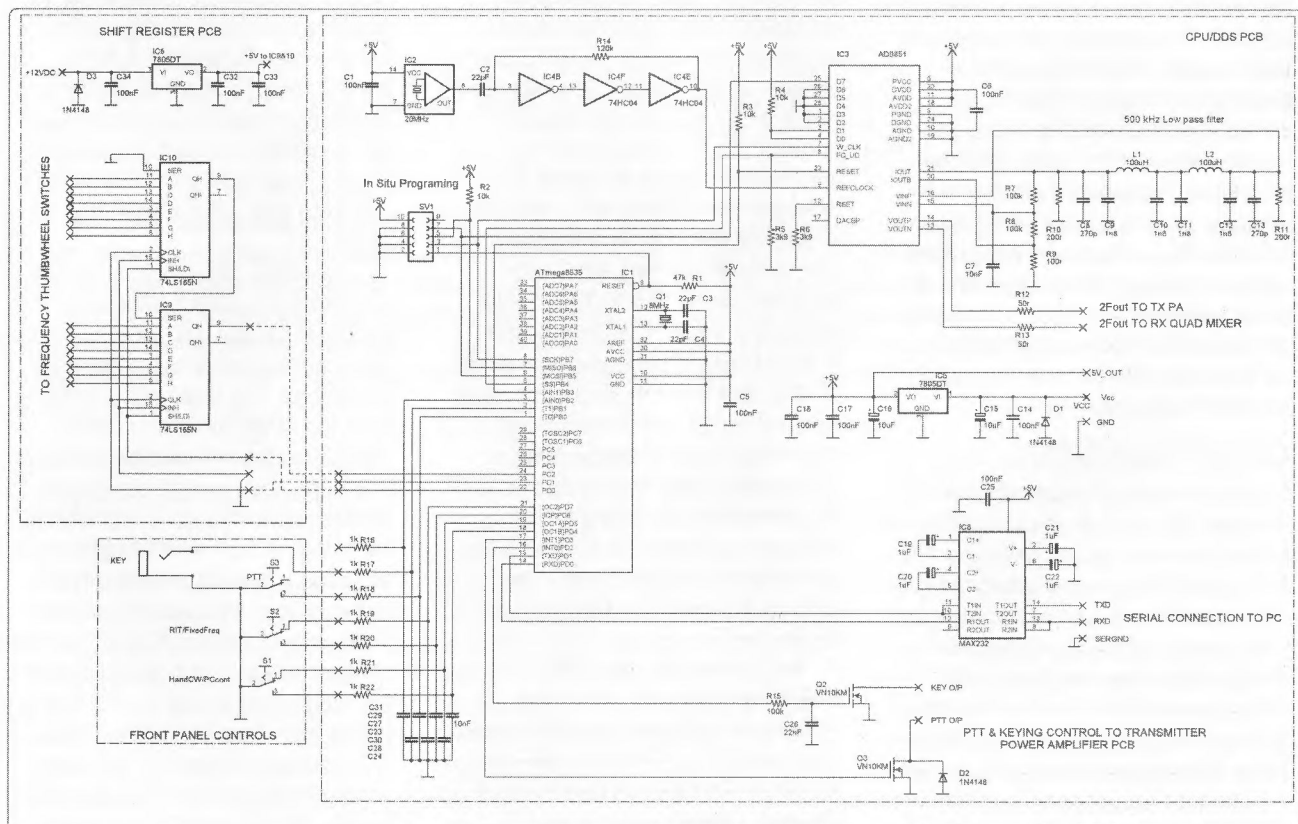
Modes 2 through 5 require the use of an attached computer for both transmission and reception of the signals. For reception of the QRSS modes it is essential to use a computer running specialist spectral analysis software, which converts the received signals into a display suitable for visual decoding. Several packages are freely available and are

commonly used: ARGO, Spectran and Spectrum Lab. A search of the web will easily locate them.

The receiver can operate in two distinct modes, 'RiT' or 'fixed frequency':

1. The RiT mode shifts the receiver local oscillator frequency so that it is always offset from the received frequency by (in this case) 1000 Hz; this generates the audio tone when receiving a CW signal by ear, for example if the receiver frequency is set to 135.900 kHz the local oscillator is set to 134.900 kHz which results in a one kHz beat note. The band-pass filter on the audio amplifier board (see Figure 8) is tuned to the same frequency as the beat note. This is the reception mode we are all familiar with when using a conventional CW/SSB receiver.
2. The fixed frequency mode is different in that the receiver local oscillator frequency is set to 135.000 kHz. This means that any

Figure 2: Processor and DDS circuit. L1 and L2 are miniature axial chokes. Except for the AD9850 DDS chip and a number of capacitors, all of the components are the leaded variety.



frequency in the band is received as an audio tone that is directly proportional to its frequency, for example a signal at 137.400 kHz appears as a 2400 Hz tone etc. When using a PC with suitable spectrum analysis software that is properly calibrated the received signal appears as a line on the screen at the correct frequency. In this way the whole band can be seen at one time and a watch kept on activity. When a signal is seen the operator can zoom-in on the frequency and decode the transmission. This is very similar to the normal Software Defined Radio applications that are now becoming common.

The transceiver serial port allows the transceiver to be controlled using a PC if desired. Except for setting the frequency (which is done using the thumbwheel switches) all other modes and functions can be accessed through the serial port by using a PC running common terminal emulator software (HyperTerminal etc.). In addition to being able to view and change most settings of the transceiver, text can be entered from the terminal which is then converted by the AVR processor to the required transmission mode (CW, DFCW, CASTLE and Hellschreiber) and speed, then transmitted. A beacon mode is provided so that specified text is sent repeatedly. The same PC can also run the spectral analysis software (for example, ARGO) at the same time as the terminal emulator and this makes the system very easy to use as the received signals can be shown on the same screen as the transmitted signals.

Circuit description

Overall control of the transceiver is achieved using an Atmel AVR processor (see Figure 2). An ATmega8535 device was originally used and then upgraded to the more readily available ATmega32 device; other pin-compatible AVR devices would be suitable if required. This device reads the various front panel switches, communicates with an attached PC (if used), controls the DDS chip, keys the transmitter

and performs T/R switching. The microcontroller is clocked at eight MHz and this clock determines dot length timing by means of regular internal hardware interrupts. Operating frequency is set using four BCD thumbwheel switches which are read by the microcontroller through two 8-bit shift registers. This was done as there would have otherwise been insufficient data lines for all the required functions and it means that the frequency selection switches could be mounted remotely from the CPU if required. The microcontroller generates a load and shift signal which then is used to shift the selected operation frequency into system. Note that the first two digits – one (1) and three (3) – are assumed by the software and the user can set the frequency to one Hz resolution. Other inputs to the microcontroller come from other front panel switches and the serial port. The RS232 serial port interface uses a common MAX232 chip. Open drain transistors are used to switch the main transmitter keying transistor and Transmit/Receive relay.

The local oscillator is generated at twice the signal frequency by an AD9850 DDS chip. Dividers in the transmitter and receiver chain convert the 2F signal to the required signal frequency. A high stability 20 MHz TCXO clocks the DDS chip and this gives the ability to precisely set the operating frequency with excellent long term stability. As the operating frequency is a small fraction of the 20 MHz clock frequency, a relatively simple 500 kHz low pass is used to clean-up the DDS output and this helps to ensure spectral purity of the output signal. The TXCO used in the prototype generated a sine-wave output and IC1 (74HC04) acted as a limiter to produce a square-wave. The limiter can be bypassed by a link if the chosen oscillator module provides a square-wave output.

The transmitter assembly (Figure 3) uses techniques that are commonly applied to switch-mode power supplies and the design is based on well proven techniques, which have been used in many

transmitter designs. The input frequency is divided by two and then fed to a FET driver which is used to drive the gates of the RF output devices. This is required due to the significant input capacitance of the output FETS and the driver chip ensures that each output FET is rapidly switched, which helps maintain the efficiency of the amplifier by reducing the period where the FET is passing through its linear region of operation. The gate drive is AC coupled with clamp diodes so that the output transistors will not draw any current if the input drive fails. The circuit is robust and will work with minor modifications to approximately 2 MHz.

The output transistors are in push-pull and their drains are connected to a tapped output transformer so that the output power can be adjusted from approximately 10 watts to full power. The ability to easily adjust output power is useful for testing aerials and for having local contacts. Note that the amplifier would be classified as a 'Class D' design and is configured in the 'current switching mode'; no bypass capacitor is installed at the centre tap of the output transformer primary. See Reference 3 for a description of current and voltage switching modes operation of push-pull amplifiers, as well as a number of transmitter designs using circuitry similar to that described in this article.

Protection circuitry is provided to protect the output transistors in the event of high SWR, DC current consumption or other undesirable conditions. The analogue signals from the SWR meter and current transducer pass to comparators and a flip-flop. In the event of an adverse situation, the comparator output goes high which toggles the flip-flop. This removes the drive to the divider chip and RF output power drops to zero. Protection can be enabled/disabled using links on the transmitter circuit board. I've found that when using paralleled FETs that the protection has been unnecessary as the FETS appear to be able to withstand most abuse.

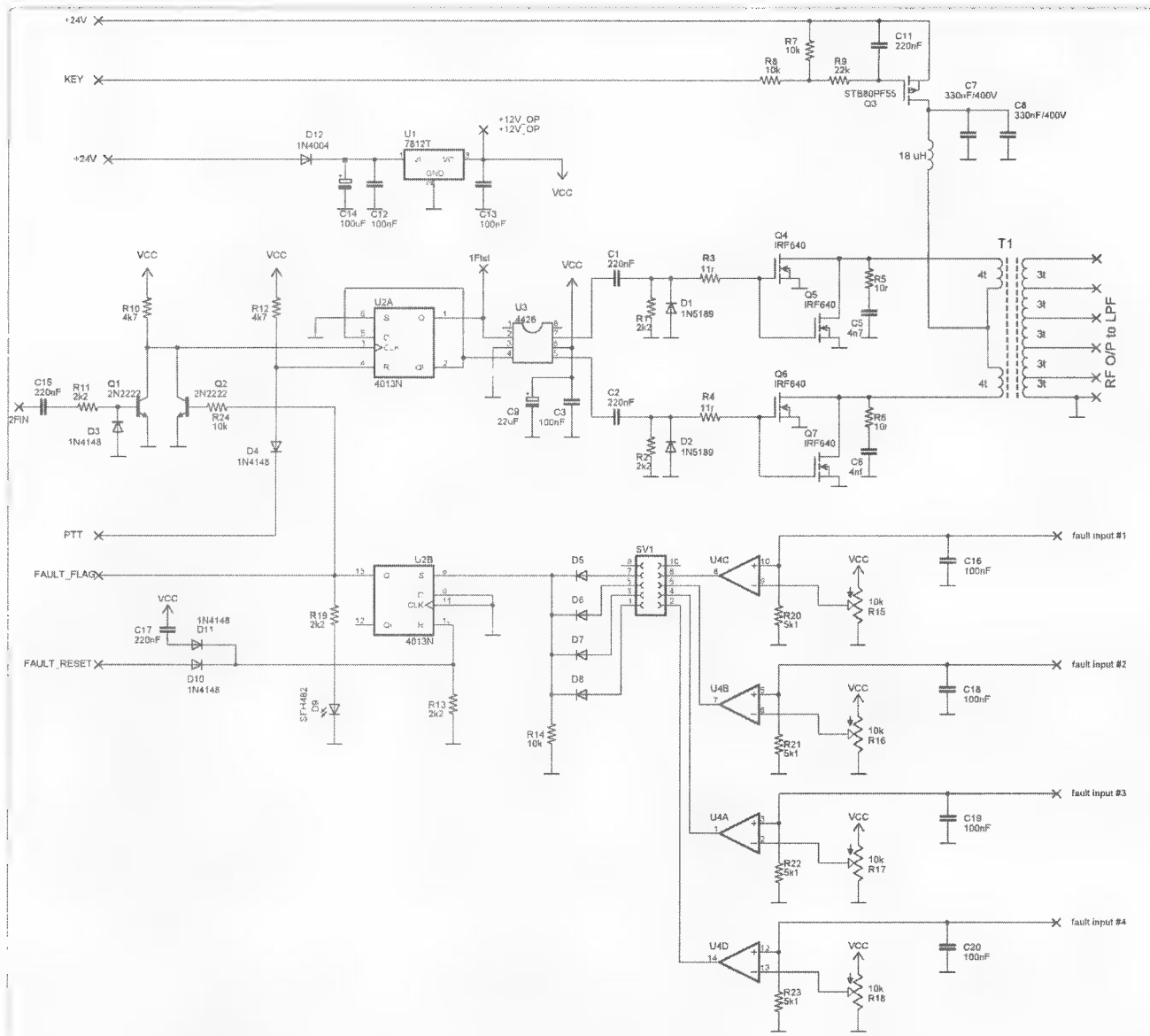


Figure 3: Power amplifier circuit. Transformer T1 is wound on an ETD49 ferrite core (3C85 material), similar cores of a suitable size and material could also be used if they are available. Choke L1 is a 28 mm toroid core (yellow and white marking) recovered from a PC power supply. Power to the output stage is enabled when the 'Key' input is grounded; RF drive to the output is enabled when the PTT input is grounded. The 'Fault Flag' output (will drive a LED) and 'Fault Reset' lines can be brought to the front panel if required so that the operator is alerted to a fault condition. Transmission can resume once the 'fault' is removed. The fault and overload protection circuitry (U2b, U4 etc) can be deleted if such protection is not required.

However, depending upon individual circumstances, it may be desirable to have some automatic protection installed.

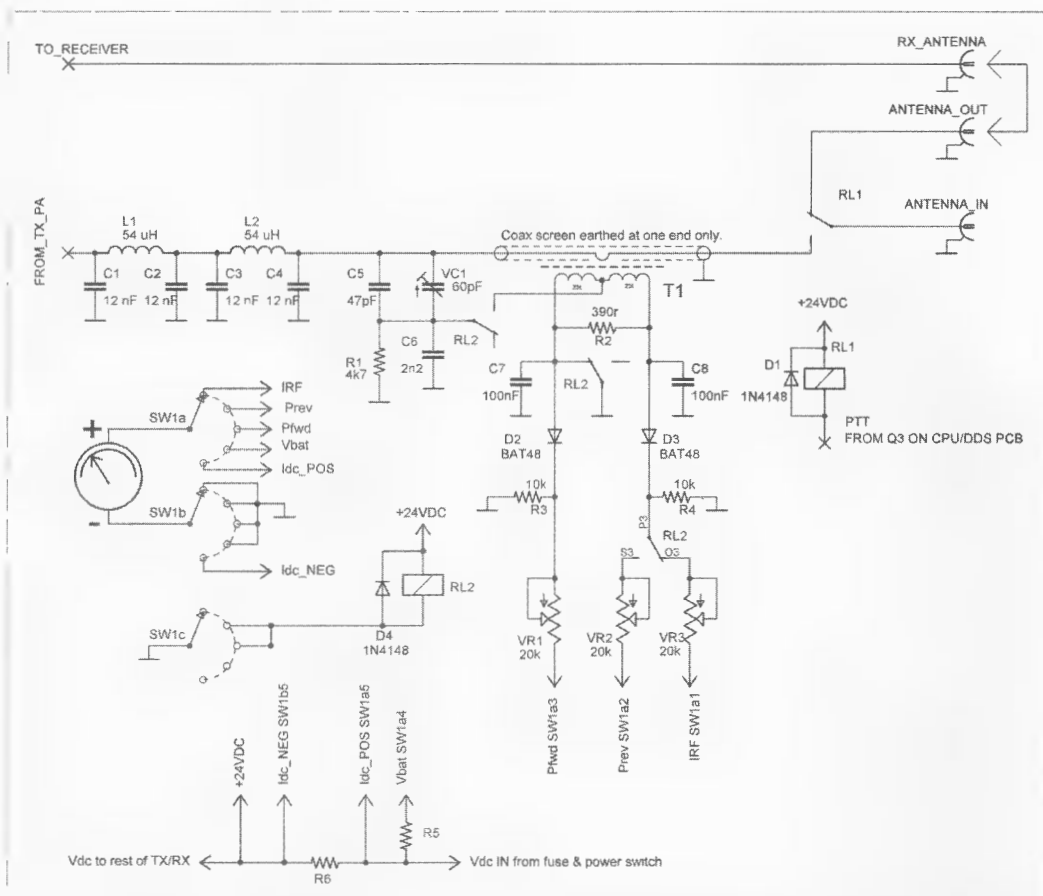
Keying of the transmitter is accomplished using a P-channel FET, which switches the supply current to the push-pull output transistors. The rise and fall time of the keyer transistor input is controlled by an RC network, this results in rise and fall times of about 10 ms which virtually eliminates key-clicks.

The transmitter output is a more-or-less pure square-wave that contains many harmonics that must be removed from the signal before it is connected to the transmitter antenna. A five pole low-pass filter is suitable and this removes the harmonics from the transmitted signal (see Figure 4). The filter 3 dB frequency is approximately 200 kHz. Harmonic removal is also assisted by the resonant transmit antenna. Also provided is a SWR meter and

RF ammeter so that the operator can monitor the tuning of the transmitter antenna and adjust it for optimum tuning. The metering circuitry appears relatively complex, but it's a standard SWR bridge. The added complexity is due to my wanting to use the transformer as an RF current transformer so that the transmitter output current could be monitored. A separate current transformer could be used and the relay switching eliminated if required.

Figure 4: Low pass filter and meter circuit.
The meter can be switched between SWR, RF current, forward power, reverse power, supply voltage and supply current measurements.

R5 & R6 should be selected for the required full scale DC supply voltage and current measurement. Separate meters could be used if desired which would result in a much simpler circuit. So that the receiver can use a separate antenna, two connectors are provided on the rear panel which allow selection of either the main transmit antenna or a separate receive antenna e.g. active whip or loop. The primary winding of transformer T1 is the



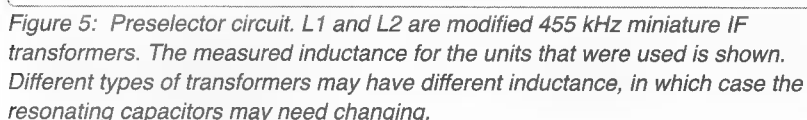
inner conductor of the coaxial cable passing through the centre of the toroid core. The secondary is 25 turns, bifilar wound, on a 15 mm 3C85 core, type 43 material would also be suitable. Potentiometers VR1 through VR3 are used to calibrate the forward and reverse power readings and RF current. This can be done using loads of appropriate and known resistance.

Relay RL2 switches the function of transformer T1 between a current transformer and SWR bridge. Measurement of the supply voltage and current is useful for measurement of amplifier DC power input and efficiency calculations. The voltage from the reverse power detector can be connected to one of the fault input comparators on the transmitter power amplifier PCB if required. This will protect the transmitter in the event of a high SWR load, although I have found this unnecessary in practice. The main cause of failure of the output transistors has been spurious oscillation and this has been eliminated by the addition of low value resistors in the gate circuit which damp any high frequency oscillation in the output devices. Note that the resistors need to be mounted as close to the FET gate connection as possible.

Moving now to the receive path, the preselector input stage (Figure 5) consists of a double tuned circuit followed by a high impedance FET amplifier and emitter follower. Other transistor types than shown could be substituted if required. The input tuned circuits determine the overall RF bandwidth of the receiver. With the component values shown the bandwidth is about three kHz. L1 and L2 are small 455 kHz I.F. transformers; the internal tuning capacitors were removed and external tuning and coupling capacitors installed. The transformer cores were then adjusted to give the required response.

Signals from the preselector filter and amplifier are passed to a pair of mixers (Figure 6) through a conventional three dB splitter. As the receiver uses a phasing method to reject the unwanted sideband (or image frequency) a pair of local

oscillator signals in phase quadrature is required. A 74HC74 dual flip-flop is configured to generate the quadrature signals, and these are fed to the mixer switches in anti-phase. The mixers are a variation of the 'H-mode' configuration which results in a mixer with very good signal handling ability. This variation eliminates the need for multiple transformers, which are required in the conventional version; however this design requires a transformer with five windings on a small toroid core. The advantage of the 'H-mode' design is that one side of the mixer switches are connected to ground and this eliminates the variation in gate 'on and off' resistance due to the local oscillator drive that can degrade the strong signal capability of switching type mixers. (See Reference 5 for more details) The amplifiers at the mixer output provide significant gain at audio frequencies,



The two audio signals in phase quadrature (I & Q signal paths) from the mixer board are passed through an all-pass filter (Figure 7) which maintains an accurate 90 degree phase difference between the two

channels over the required range of frequencies. The output from each filter channel is then added together, and as a result of the quadrature phase relationship between the audio paths and the local oscillator, the audio image (the unwanted sideband) is cancelled out. Small amplitude differences between the I and Q channels can be corrected by means of potentiometer VR1 at

the summing junction. The wanted signal is then passed through an audio band-pass filter. The network shown has upper and lower cut-off frequencies of 2.7 kHz and 300 Hz respectively.

This design is taken from Reference 4 which gives a very good description of how phasing networks function. The phasing network resistors are standard 1% tolerance and the required values were made up from series connected resistors. The capacitors were hand selected from a bulk purchase of 100 polyester capacitors and were chosen from the batch so that all the capacitors used had matching values. The NE5532 dual amplifiers have a wide bandwidth and low noise, making them ideal for this application.

Following the band-pass filter is another gain stage followed by the audio power amplifier, which feeds a loudspeaker or headphone (Figure 8). For situations where aural contacts can be achieved, a CW band-pass filter can be selected. The filter has a 'Q' of 4 and a centre frequency of 1000 Hz, so the 3 dB bandwidth is 250 Hz. Selecting this filter significantly improves the signal to

Figure 6: Quadrature mixer circuit. T2 and T3 are 12 5-filar turns on T50-43 cores. T1 is 16 bifilar turns on a T50-43 ferrite toroid core. Amplifiers U1 and U2 must be low-noise types. OP37 or similar devices are ideal as they have a low noise figure and significant gain.



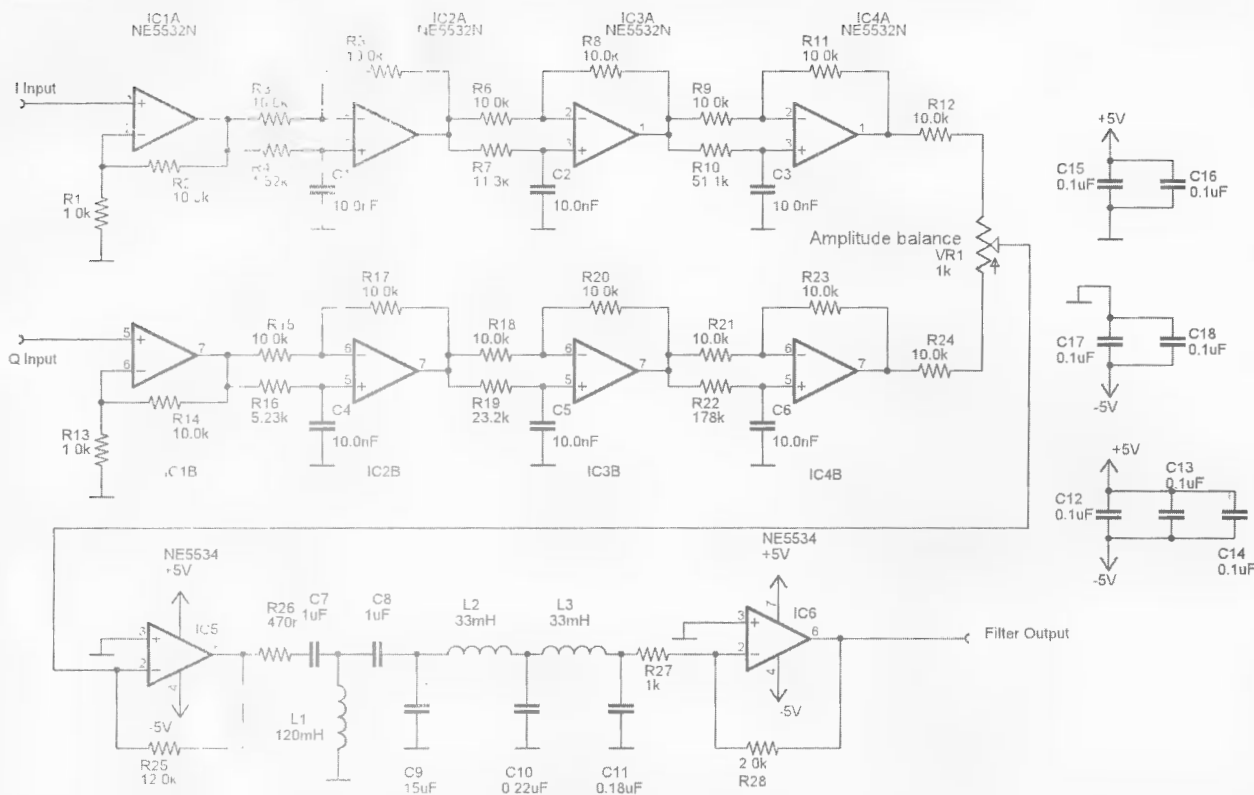


Figure 7: Audio phase shift and band-pass filter circuit. The resistors in the phasing circuitry can be made up from series combinations of standard values. The values of the capacitors in the phasing network don't need to be exactly 10 nF but should be closely matched if possible.

noise ratio of the received signal. So that signal levels are not disturbed, an amplifier with the same gain as the band-pass filter is fitted; thus the audio output level doesn't change when the filter is enabled or disabled. The final amplifier (U4) amplifies the signal to drive a loudspeaker; it also has a 'mute' input which suppresses any receiver noise when the set is transmitting. This mute signal is taken from the CPU board PORTD3 output which controls the T/R relay.

Power to the transceiver was supplied from a 24 VDC source and three terminal regulators and a small DC-DC converter were used to provide the various supply voltages to the modules. No detailed information is provided for the power supply as constructors will probably want to make their own arrangements; depending upon what parts they have available. The voltages required are 24 V, 12 V and ± 5 V.

Components and Construction

The transceiver was constructed on a simple home made chassis with CPU/DDS and receiver modules underneath and the transmitter, low-pass filter and power supplies on the top of the chassis. A front panel holds the operator controls and meter. The final design will be largely dictated by what components and facility the constructor has at his or her disposal.

Screened cable was used for all low level signal circuitry and extensive bypass and decoupling capacitors installed where power passed from one module to another. Appropriate feed-through capacitors or coaxial connectors were used whenever power or signals passed through chassis partitions.

Most of the components are readily available, particularly the power FETs. I purchased high voltage capacitors for the low-pass filter from Rockby Electronics (www.rockby.com.au) who also

has a selection of suitable ferrite cores and transformer assemblies. The AVR processor and Analog Devices DDS chip are available from Futurlec (www.futurlec.com.au). Other specialised components were purchased through RS components (<http://australia.rs-online.com>) or Farnell (<http://au.farnell.com/>). Many suitable components (ferrite and semi-conductor) can be found in discarded switch-mode power supplies and some careful experimenting will soon indicate how useful such parts might be.

The 20 MHz TXCO was purchased from Hy-Q International Pty Ltd (<http://www.hy-q.com.au>) some years ago, but similar products are also available from other suppliers. Standard can type oscillators could be used, but frequency accuracy and stability may not be as good.

Software for the AVR Processor and artwork for the various printed circuit boards (in EAGLEcad format) are available to anyone who would like to build a similar transceiver.

Adjustments and Testing

There are relatively few adjustments required before the transceiver can be used. The main thing to ensure is that all wiring is correct before turning it on!

Before testing, the transmitter should be connected to a suitable 50 ohm dummy load and the protection circuitry (if fitted) disabled by removing any links fitted to SV1. Starting with a low power tap selection, output power should be seen on the forward power meter when the transmitter is energised. Switch to reverse power and adjust VC1 in the SWR meter circuitry so that the meter reads zero. The forward and reverse power meter readings can be calibrated using the associated potentiometers (VR1 and VR2) in the SWR meter circuitry. The RF ammeter can be calibrated by measuring the voltage across the dummy load, calculating the associated current and adjusting VR3 so that the meter shows the correct value.

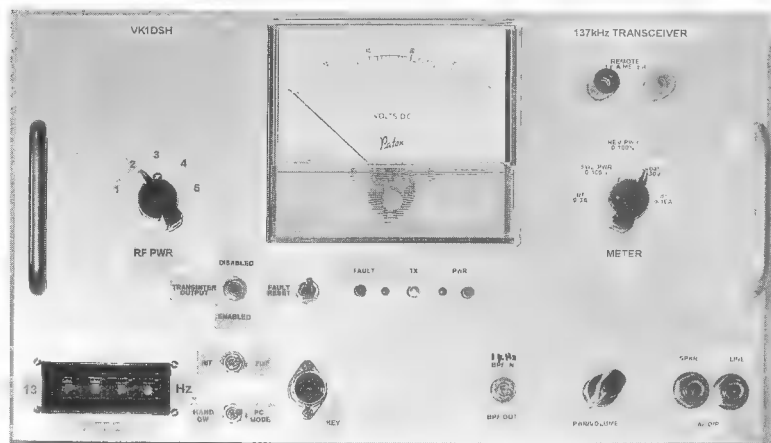


Figure 9: Front view of the transceiver. A useful addition was the 'Transmitter Output Disable' switch so that the set could be worked on without the risk of accidentally transmitting into receiver amplifiers or active whip circuitry. The switch disconnects the keyer transistor so that no drain voltage can be applied to the output power transistors.

Adjustment of the protection circuitry is done by re-installing the wanted jumpers on SV1 and adjusting the comparator trip potentiometers until the desired level of protection is achieved with whatever fault level is applied.

Constructors will have their own specifications for this aspect of the design. The transmitter can now be run at full power and at least 200 watts should be generated, efficiency is typically greater than 80 % at this power level.

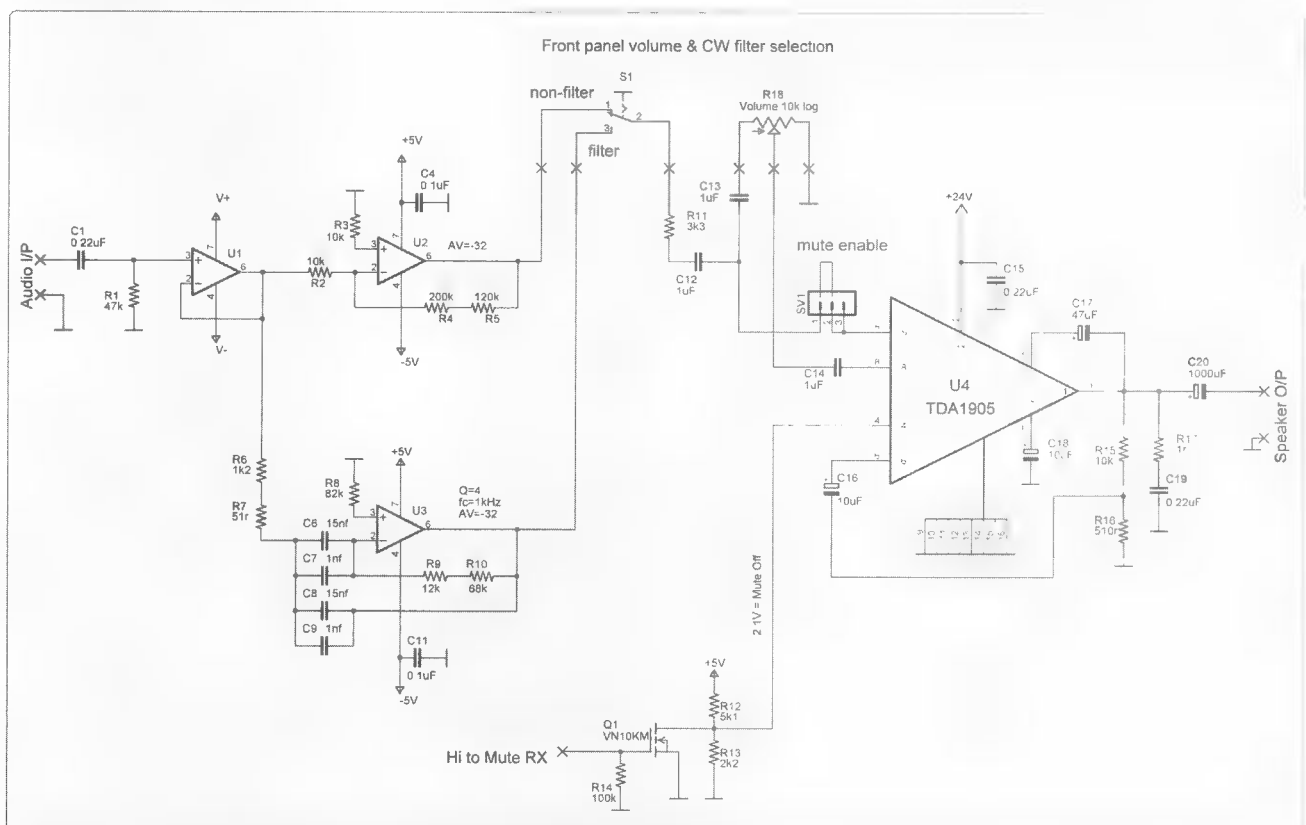


Figure 8: Narrow band CW filter and audio power amplifier. Amplifiers U1, U2 & U3 can be any suitable low-noise operational amplifiers that are suitable for audio use e.g. TL071, NE5534 etc. The in-built mute circuitry of the TDA1905 can be disabled by removing link from SV1.

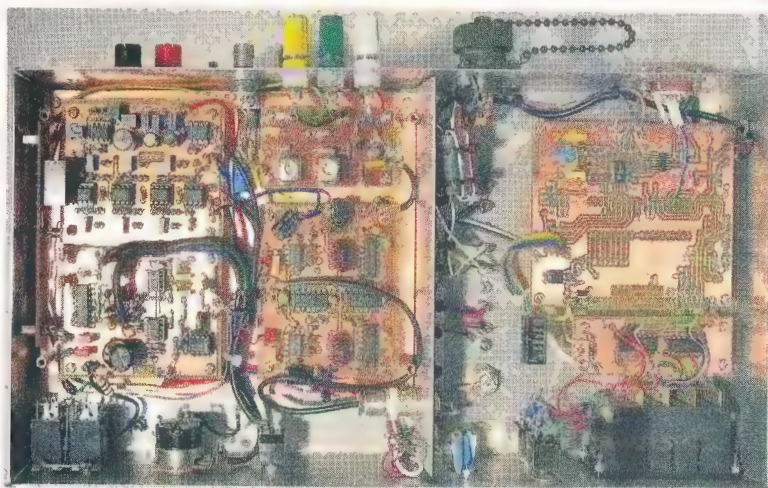


Figure 10: Underside of the transceiver chassis showing (from left to right): the receiver modules, CPU/DDS, shift register and thumbwheel switches. Terminals on the rear panel provide power to external circuitry such as loop and active antennas.

The receiver requires few adjustments. The tuned circuits in the preselector circuit (Figure 5) should be peaked for maximum response; using the values given in the schematic should give a response that covers the entire band.

Assuming the components selected for the audio phase shift network (Figure 7) were carefully selected, the phasing network should work by just adjusting the 'Amplitude Balance' control (Figure 7, VR1) to the centre of its range. Accurate adjustment can be done in the following way:

1. Set the receiver to 'fixed frequency' mode, this sets the receiver local oscillator to 135.000 kHz. Set the signal generator to 136.000 kHz and inject a weak signal into the mixer input, that is, bypassing the input RF preselector. If the mixer output I & Q channels are correctly connected a one kHz tone should be heard from the receiver, if nothing is heard swap the I & Q outputs from the mixer to select the other image frequency and the tone should be heard. If still nothing is heard, there is a fault somewhere else and that will have to be fixed before proceeding.
2. Now set the signal generator to 134.000 kHz, the one kHz tone should be much weaker.

Adjust the 'Amplitude Balance' control (VR1) to minimise the volume of the tone.

3. Reset the signal generator back to 136.000 kHz and the tone should be much louder. The amplitude difference between the two frequencies is a measure of the image suppression and in the prototype receiver it was measured and found to be approximately 47 db which is quite adequate for this application. If necessary, see References 1, 2 and 4 for more details about adjusting phasing type receivers.

Conclusion

The transceiver described in the above pages has been in use for nearly one year and has proven itself to be a reliable and high performance design. Its signals have been received in New Zealand and a number of QSOs using either hand sent CW or one of the other QRSS modes have taken place. Receiver sensitivity and transmitter power output are more than adequate for working DX when combined with a suitable antenna. Thanks go to Bill VK7MX for reviewing this article and for his helpful suggestions.

References

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2. A phasing type transceiver for 144 MHz. *Amateur Radio*. Two parts: August & September 2009, Volume 77, No 8 & 9.
3. *LF Today a guide to success on 136 and 500 kHz*. RSGB. ISBN 9781 9050 8636 8 Available from the WIA bookshop.
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Figure 11: Top view showing (from left to right): the power amplifier module (beneath the fans), low-pass filter and meter circuit and power supply box. The fans are only necessary if running at full power for an extended period of time. Otherwise they are optional. The home-made current shunt can be seen on the top right-hand side of the picture.

